This approach heavily emphasizes quantity over quality since each weapon individually might not be highly effective. Nevertheless, this combination of many air defense systems could potentially provide nine to sixteen helicopter engagements per battalion task force at ranges between three and six kilometers, more than double those provided by any of the other options. If only half of the fighting vehicles were allocated to provide air defense, six to ten engagements at the same ranges would still be possible. Indeed, if only a quarter of the fighting vehicles participated in the air defense role, this alternative would still provide more total engagements than any of the other alternatives. Providing so many systems with an additional capabiity would not be cheap and could require an investment of almost $4 billion--$3.5 billion over the next five years and $500 million thereafter. Consequently, from 1987 through 1991 almost $2 billion more would be required than is currently included in the Army's plan (see Summary Table 3). Still, this alternative would provide the greatest number of potential engagements of any of the alternatives.

This approach could introduce several problems, however. Questions arise concerning the availability for air defense of systems, such as the Bradley and tanks, whose primary role is fighting other ground weapons. In addition, soldiers manning systems like the Bradley and tanks would have to be trained in both ground combat and air defense, and leaders would have to coordinate 700 or more systems capable of engaging both enemy aircraft and ground targets. These concerns, though real, should not negate the potential for self-defense that resides with the Army's current weapon systems. Indeed, the Army appears to be planning to improve the Bradley's ability to engage helicopters, although not to the extent envisioned in this alternative.

THE MAIN ISSUE: QUANTITY VERSUS QUALITY

The alternatives in this study are largely homogenous strategies which could, in actuality, be combined. The options were chosen, in part, to dramatize the trade off between the quality and quantity of air defense systems. In terms of increased air defense capability, the optimal solution would be to field large numbers of highly capable air defense systems. This is not a practical choice, however, because of cost. Thus, defense planners may have to choose between quality and quantity.

CHAPTER I

INTRODUCTION AND BACKGROUND

The U.S. Army's plans for improving its divisional air defenses were dealt a severe blow when Secretary of Defense Caspar W. Weinberger cancelled DIVAD, the Army's new anti-aircraft gun. Designed in the mid 1970s, the DIVAD was intended to replace the 20-year-old Vulcan anti-aircraft gun, currently in the Army's inventory, and to defend the Army's most forward deployed forces against potential attack by enemy fighter bombers and attack helicopters. When finally produced and tested during 1984 and 1985, however, the DIVAD proved incapable of overcoming the threat postulated for the 1990s. Furthermore, its unit cost--over $6 million--severely limited the number of guns that could be purchased and deployed with Army forces. Consequently, Secretary Weinberger, in an unprecedented move, cancelled the program in August 1985, leaving the Army, once again, with an outdated and inadequate air defense system for its forward deployed forces.

In the wake of the cancellation, the Army was forced to develop a new plan to improve its forward air defense. 1/ Although each Army division does include weapons designed specifically for air defense, they are, for the most part, old and ineffective against even today's threat, much less that anticipated in the 1990s. The Vulcan 20mm anti-aircraft gun, for example, entered the inventory in the late 1960s and does not have adequate range to destroy modern enemy aircraft before they launch or fire their weapons. Other air defense weapons have similar defects. Thus, the Army is currently evaluating those air defense systems that could be available quickly and have the potential to provide the short-range air defense that the Army's forward units currently lack.

THE MODERN BATTLEFIELD

Today's Army includes many diverse types of forces designed to fight the land battle anywhere in the world. The units assigned the mission of deterring potential ground attacks on U.S. and allied forces in NATO, and subsequently defending those allies should deterrence fail, are the Army's heavy armored and mechanized divisions (see Figure 1). These so-called "heavy divisions" include about 17,000 soldiers equipped with, among other

1. See the appendix for more details of the Army's current plan.

things, 300 or more M1 main battle tanks and 330 to 370 Bradley Fighting Vehicles. Groups of tanks and fighting vehicles that form the "maneuver elements" of a division would provide the first line of defense against any potential attack by enemy armored forces.

Combat units containing a mix of tanks and fighting vehicles are supported by many other units, such as field artillery, medical, transportation, and engineer groups (for constructing trenches, obstacles, and other fortifications). In addition, all Army divisions include helicopter units for attacking enemy armored forces and transporting cargo and troops. Finally, the U.S. Air Force, when possible, provides air protection and support to U.S. forces on the ground.

The major opponent of NATO is the Warsaw Pact alliance, whose forces include a similar array of air and ground weapons and combat units. During the initial phases of an attack in Central Europe, Warsaw Pact forces would probably outnumber NATO forces by as much as two to one, perhaps by more in specific locations. In addition, attacking ground forces would be supported by both high performance aircraft, such as fighter bombers, and heavily armed attack helicopters. Although air attackers would probably not be as numerous as those on the ground, they could cause considerable damage to U.S. armored forces in the absence of adequate defenses.

History provides little guidance to the efficiency of modern air attackers using sophisticated weaponry. Recent employment of aircraft against armored targets is limited to the Arab-Israeli conflicts in the Middle East. During the 1982 incursion into Lebanon, Israeli attack helicopters and close air support aircraft were credited with destroying and immobilizing Syrian tanks. With only limited recent wartime evidence, analytic results must be used to gauge the possible impact of tactical aircraft on opposing armored forces. According to a recent independent analysis of the European conventional balance, attack helicopters of the Warsaw Pact potentially could destroy 1,950 armored vehicles in two weeks. 2/ Recent Army analyses attribute as much as a quarter of all potential U.S. losses in a short, intense battle to attack by enemy aircraft. 3/

Thus, the concern of the U.S. Army to provide a capable air defense for its heavy forces stationed with NATO is readily apparent. The nature of the threat and the defenses needed to counter it are explored in Chapter II.

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2. Barry Posen, "Measuring the European Conventional Balance," *International Security* (Winter 1984-1985).

3. Department of the Army, Tradoc Studies and Analysis Agency (TRASANA), *Sgt. York Comparative Analysis* (October 1985).

Figure 1.
Corps Sectors of Military Responsibility in NATO's Central Region

SOURCE: Adapted by CBO from Richard Lawrence and Jeffrey Record, *U.S. Force Structure in NATO* (Washington, D.C.: Brookings Institution, 1974), p. 31 and also from U.S. Army materials.

NOTE: NORTHAG (Northern Army Group) and CENTAG (Central Army Group) are the two subdivisions of NATO forces in West Germany. The line dividing the two runs from Belgium through West Germany, just south of Bonn, and into East Germany.

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CHAPTER II

THE POTENTIAL SOVIET AIR THREAT AND U.S. AIR DEFENSE IN EUROPE

The most formidable potential threat likely to be encountered by U.S. forces deployed as a part of NATO in Central Europe is that posed by the Warsaw Pact. The Warsaw Pact as a whole, and the Soviet Union in particular, undoubtedly field more aircraft of great sophistication and capability than any other potential U.S. enemy. This discussion, therefore, focuses on defending U.S. forces from attack by Soviet aircraft in Europe. In keeping with the sectors of military responsiblity within NATO (shown in Figure 1), the U.S. Army would rely on its own air defenses to counter attacking Soviet aircraft.

THE SOVIET AIR THREAT

Over the past 10 years, Soviet attack helicopters have come to assume more and more of the responsibility for potential strikes against NATO armored assets positioned close to the front line of battle, compared with the role assigned to fixed-wing aircraft. In 1972 it was generally believed that the Soviet Union did not possess helicopters capable of antiarmor warfare. By 1975, however, the Soviets were thought to have 200 gunships, including both Hip and Hind helicopters. 1/ While these two large helicopters can carry troops, they are also equipped with guns, rockets, and antitank missiles. Ten years later, various sources credit the Soviet Union with some 1,300 attack helicopters, primarily the heavily armored Hind, but also a small number of the recently introduced Havoc. 2/ Because this new attack helicopter is more agile than either the Hip or Hind, it seems to be designed specifically for the antiarmor role. One final piece of evidence that supports an increased role for Soviet helicopters in attacking armored units is their recent reassignment from larger to smaller organizations, making them more a part of specific ground attacks.

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1. John Collins, *U.S.-Soviet Military Balance 1960-1980* (McGraw-Hill, 1980).

2. International Institute for Strategic Studies, *The Military Balance 1980-1981* (1980) and *1984-1985* (1984); and Department of Defense, *Soviet Military Power* (1985).

In contrast with the growth in its helicopter fleet, the total number of Soviet fighter and ground attack aircraft has remained relatively steady at about 2,600, although they have increased in capability during this period (see Table 1). The U.S.S.R. has also recently introduced a new close air support airplane, the Frogfoot, that is specifically designed to perform the antiarmor mission.

Threat Tactics

A brief discussion of the tactics of air attacks should clarify the helicopter's tactical advantage. Both fighter bombers and helicopters attacking maneuver elements close to the front would attempt to minimize their exposure to enemy air defense weapons by approaching the target area at as

TABLE 1. SOVIET TACTICAL AIRCRAFT INVENTORIES, 1975, 1980, AND 1985

Aircraft	1975	1980	1985
Attack Helicopters			
Hip E	75	125	150
Hind A/D/E	125	750	1,100
Havoc	0	0	10
Subtotal	200	875	1,260
Ground Attack Fighters			
Fishbed J/K/L/N	1,600	1,000	160
Flogger D/J	450	400	730
Fitter A/C/D	600	805	980
Fencer	0	370	630
Frogfoot	0	0	75
Subtotal	2,650	2,575	2,575
Total	2,850	3,450	3,835

SOURCES: John Collins, *U.S.-Soviet Military Balance 1960-1980* (McGraw-Hill 1980); and International Institute for Strategic Studies, *The Military Balance 1980-1981* (1980) and *1984-1985* (1984).

low an altitude as possible. 4/ Army field manuals speculate that most attacks on ground targets near the front line would take place at altitudes of less than 300 meters (m) and at speeds of less than 500 knots. Helicopters can carry out such low-level attacks with greater efficiency and less risk than can fighter bombers.

Fighter Bombers. Fixed-wing aircraft could deliver ordnance using either a "pop up" or "laydown" technique. A pop up profile--a low-altitude flight to the target area followed by a steep ascent to a high-altitude vantage point to locate targets--could be used to deliver conventional bombs, rockets, guided missiles, or cannon rounds and has the advantage of providing ample time to find targets and to allow accurate weapon delivery. As the aircraft pops up to weapon delivery altitude (600 to 2,300m) and then dives to release weapons some 500 to 1,500m from the target, however, it would be vulnerable to both detection and attack by opposing air defense weapons.

A laydown weapon delivery, on the other hand, would minimize aircraft exposure to air defense fire because the pilot flies at a constant altitude of about 150m at maximum feasible speed (350 to 500 knots) to deliver ordnance at low altitudes. This technique, however, would limit the types of ordnance, target acquisition capability, and delivery accuracy. Thus, although fixed-wing aircraft could deliver ordnance with greater speed than helicopters, they would have to approach within short ranges (0 to 1,500m) of their targets and fly at altitudes of 100 meters or more.

Helicopters. On the other hand, attack helicopters could approach targets close to the front line at the lowest possible altitude, possibly below tree level, using terrain, trees, and buildings to shield or mask their movements from enemy air defenses. By operating in coordination with observers on the ground in order to estimate when they are within attack range of their targets but still on their own side of the forward battle area, helicopters could use quick pop ups above terrain and foliage obstacles to locate and fire upon targets.

Guided antiarmor missiles pose the greatest threat to forward deployed tanks and fighting vehicles. The AT-6 Anti-Tank Guided Missile (ATGM), recently introduced into the Soviet inventory, would inflict the greatest damage while minimizing helicopter exposure. Both the Hind and the Havoc are helicopters judged to be capable of carrying at least four of these missiles which the helicopter gunner could guide to their targets

4. The front line is referred to in Army publications as Forward Line of Own Troops (FLOT).

through radio links. Various sources ascribe a five to seven kilometer (km) maximum range to the AT-6. 5/

It is likely that, within the next 10 years, the Soviets will introduce a replacement for the AT-6 that would be similar to the new laser-guided Hellfire missile carried on the latest U.S. attack helicopters. The new ATGM would be guided to its target by laser radiation reflected from the target's surface. Semiactive missiles, as these are known, require that targets be illuminated, or "designated," by a laser which can be mounted on the same platform as that launching the missile (self-designation) or on some other platform (indirect designation) either on the ground or in the air. Although relatively long ranges theoretically can be achieved by semiactive laser missiles, in practice maximum operational ranges are limited to about seven km by visibility constraints when the same platform is used to launch the missile and designate the target. Relying on a separate laser designator could increase the maximum helicopter-to-target range to 10km.

After popping up, the helicopter would hover in an attempt to locate, fire upon, and subsequently guide its missile to the target. During this period the helicopter would be exposed to detection and attack by air defenses. If the helicopter pilot should come under attack, however, he could descend rapidly so as to place trees, hills, or buildings once again between himself and would be attackers.

For all the above reasons, both the United States and the Soviet Union have come to rely increasingly on helicopters, rather than fixed-wing aircraft, for the potential destruction of armored vehicles in the front battle areas. The emphasis for air defense, therefore, has shifted from that of countering fixed-wing aircraft to that of overcoming attack helicopters, although the mission against fixed-wing attackers still remains.

DEFENDING AGAINST THE THREAT

The Army could not expect much assistance from Air Force fighter aircraft in routing enemy attack helicopters. Historically, the United States has relied on a combination of ground-based air defense systems and interceptor aircraft to protect its ground troops from air attack. Interceptor aircraft, however, are not designed to attack slow-moving, very low-altitude attack helicopters and, as a consequence, they could not provide an effective defense against them.

5. Department of the Army, *United States Army Weapon Systems 1986* (January 1986); and Flight International, *World Missile Directory* (February 1983.)

Fighter aircraft are ineffective against enemy helicopters for two reasons. First, low-altitude helicopters are very difficult to detect from above, especially when they are hovering. The radar returns from a slow-moving or hovering helicopter are obscured to a great extent by the reflections from nearby trees and hills. This phenemenon, called ground clutter, would prevent a fighter aircraft from using its radar to find enemy helicopters. Second, even if an interceptor aircraft should locate an enemy helicopter, its weapons, which are designed for use against high-speed aircraft, would not work well against helicopters close to the ground. Although the Air Force's interceptor's might be able to provide more effective defense against enemy fixed-wing aircraft than against helicopters, there is no guarantee that they will be able to stop them all. Thus, the Army must depend on ground-based air defense systems to protect maneuver elements at the front.

Types of Air Defense Weapons

Army air defense assets are assigned the mission of destroying, driving away, or reducing the effectiveness of enemy helicopters and high-performance aircraft attacking friendly assets. The Army has traditionally performed this mission using a combination of widely disparate air defense weapons.

Highly sophisticated U.S. missile systems, such as Hawk and Patriot, provide umbrella coverage for long ranges and high altitudes, particularly against high-performance enemy bombers, fighter bombers, and intercepter aircraft. Patriot has the longest range of all the Army's air defense systems and forms the centerpiece of the Army's European air defense. It is designed primarily to prevent enemy bombers and accompanying aircraft from penetrating into West German airspace and attacking NATO airbases. Patriot fire units would not typically be assigned to defend particular Army organizations; rather they are designed to protect the entire European theater. On the other hand, each corps (the managerial unit directly above the divisions) and some Army divisions are typically supported by at least one Hawk battalion with 24 launchers. Hawk is designed to provide medium-range coverage (to about 40km) against attacking enemy aircraft flying at low to medium altitudes--from 0 to 15,000m--over an entire divisional area.

Systems such as Hawk and Patriot, which are designed to destroy enemy aircraft at ranges beyond 10km must rely on radars to detect those aircraft. These long-range air defenses would typically be located to the rear of the battle area--at least 10km from the front in order to protect delicate radars and missile launchers from the effects of enemy artillery.

From this position, they would be unable to detect aircraft flying at low altitudes so as to use terrain, buildings, and trees as a shield from air defense radars. Thus, each Army division also includes air defense weapons that are limited in range (Short Range Air Defenses or SHORADs). These are smaller and more mobile than the longer-range systems and would be deployed close to the assets that they are assigned to protect. The Army currently deploys three short-range weapons: Chaparral, Vulcan, and Stinger, which are described in Chapter III (see Figure 2).

SHORAD systems are responsible for defending command posts, supply depots, field artillery units, and groups of armored combat vehicles. In order to provide continuous coverage of maneuver units, such as tank or mechanized infantry battalions that typically include 50 to 60 tanks and armored fighting vehicles, SHORAD systems must be able to accompany defended units as they travel in convoy or proceed into battle. It is essential, therefore, that a system assigned to protect the maneuver elements be able to operate while moving or shortly after stopping.

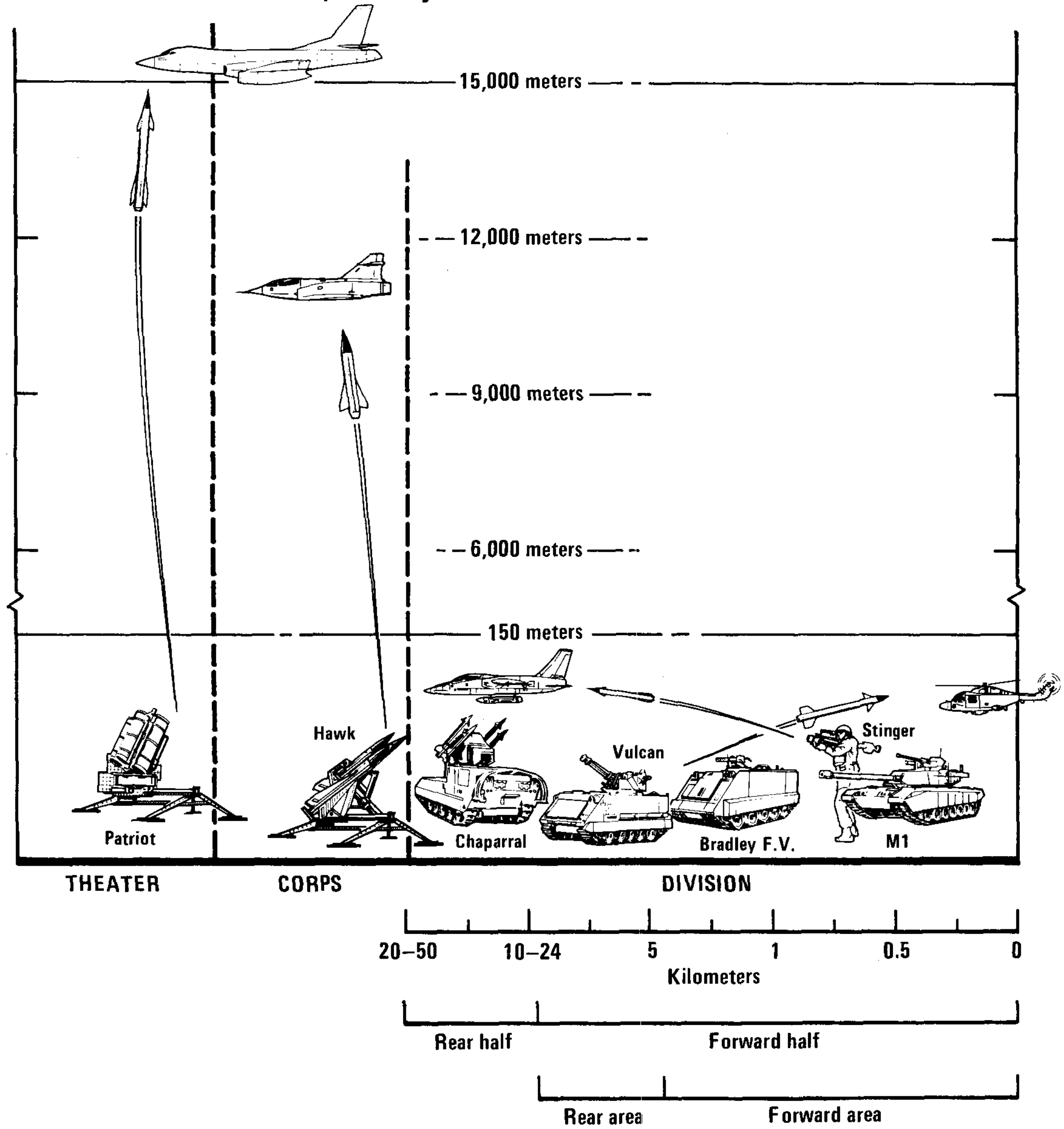
Air Defense Survivability

Air defense assets must also be able to survive in the very hazardous modern battlefield if they are to perform their mission. Air defense weapons close to the forward battle area, however, would themselves come under both direct fire from enemy systems, such as tanks and antitank weapons, and indirect fire from enemy artillery. Inasmuch as air defense weapons are not typically designed to withstand antitank munitions, they would not long be able to survive if positioned too close to the front line. Furthermore, SHORAD systems typically have rather distinctive physical profiles and would stand out even among large numbers of tanks and other armored vehicles. Considering the small number of air defense systems protecting a typical maneuver element, these distinctive systems would soon become lucrative and early targets for the large numbers of enemy weapons that would most likely be included in an opposing force. 6/ Therefore, according to Army field manuals, air defense weapons should be placed **behind** the maneuver elements in what is called an "overwatch position." 7/ Thus, in order to survive and still perform their air defense mission, effective air

6. A battalion-sized task force of 19 M1 tanks and 30 fighting vehicles, including Bradley fighting vehicles, improved TOW vehicles, and cavalry fighting vehicles, would typically include four SHORADs and could be opposed by as many as 91 Soviet tanks and 85 ATGM-equipped armored personnel carriers.

7. An overwatch position is one that enables an air defense unit to remain behind the asset it is defending in a relatively safe location while still providing coverage above and in front of the defended asset.

Figure 2.
U.S. Air Defense Weapons Systems



defense systems must have sufficient range to be able to cover the distance from their rearward position to standoff helicopters attacking the maneuver assets.

DESIRED CHARACTERISTICS OF AN EFFECTIVE AIR DEFENSE

Based on the air threat and potential battlefield environment in Central Europe, it is possible to identify several features that would be desirable in an air defense capable of destroying standoff helicopters. Among other things, the threat and environment determine the required range and number of individual air defense units. These two characteristics--range sufficient to reach out and negate an enemy helicopter's standoff capability and numbers large enough to ensure multiple engagements of each attacking helicopter- - are the keys to fielding an effective air defense.

Air Defense Systems Needed in Large Numbers

In Central Europe, where the landscape is generally hilly, the use of terrain to hide movements would be particularly advantageous to fighter bombers and attack helicopters and disadvantageous to the U.S. air defense systems attempting to track them. This situation would be exacerbated by the extremely perilous environment in which the air defense unit would have to operate. To provide an effective shield, therefore, air defense systems would have to be deployed in large numbers. They could position themselves on high points that would afford them good views of likely aircraft approach routes. Such sites, however, would also be exposed to enemy artillery, tanks, and antitank weapons. Air defenders at the front, therefore, would have to sacrifice visibility in the interest of survivability.

Probabilities illustrate the importance of having large numbers of widely dispersed air defense systems. The probability that a particular air defender, located in a forward position immediately behind the armored units, would have a clear line of sight--unobstructed by trees or hills--to a fighter bomber six km away at an altitude of 100m is only 50 percent. Thus, only half the air defenders randomly placed in the forward area would be expected to see this aircraft. The other half would have their view "masked" by hills or other impediments. The same limitations apply to sighting helicopters, of course, and, since helicopters can safely operate at much lower altitudes, the likelihood of seeing them at long ranges is much lower. As an enemy helicopter "stands-off" from its target at a typical hover altitude of 20m, the probability of locating it at six km is only 21 percent. 8/ Thus, only about one-fifth of the deployed air defense systems would be able to "see" a helicopter at this distance. The remaining 79 percent would have their view blocked by hills or other terrain features. Since the likelihood is small that any one particular air defense unit would be in position to locate a helicopter when it pops up to attack, large numbers of dispersed units would be needed to guarantee that at least one or preferably two air defenders would be in position to see it. 9/

The number of air defenders needed would increase with the standoff range of the helicopter (see Figure 3). If an enemy helicopter was able to engage a U.S. battle formation from five km away, as many as eight air defense units could be needed to achieve a 50 percent probability that at least two air defenders could see the target (assuming that the air defense units were situated one km behind the battle formation). If the helicopter could increase its standoff range to six km, the number of air defenders required would increase to 11 under the same assumptions.

Effective Range and Air Defense Density

Of course, locating an enemy aircraft would not be all that was required to destroy it. An air defense unit would also have to be able to shoot at, or engage, the attacking helicopter or fighter bomber. Thus, the gun or missile associated with the system would need enough range to engage the enemy aircraft at its operating distances. As discussed previously, the air defense system would have to compensate for both its own position behind the armored forces and the helicopter's standoff range. Thus, air defenses that are set back one km would need an effective range of more than six km in order to defend against a helicopter that could standoff and attack a tank formation from five km.

In order to deter enemy aircraft, air defense units would typically be dispersed along lines roughly parallel to the front. The number of air defense units per kilometer of front can be defined as the air defense density. The density required to defend against a helicopter attack is a function of the helicopter standoff range and the effective range of the air

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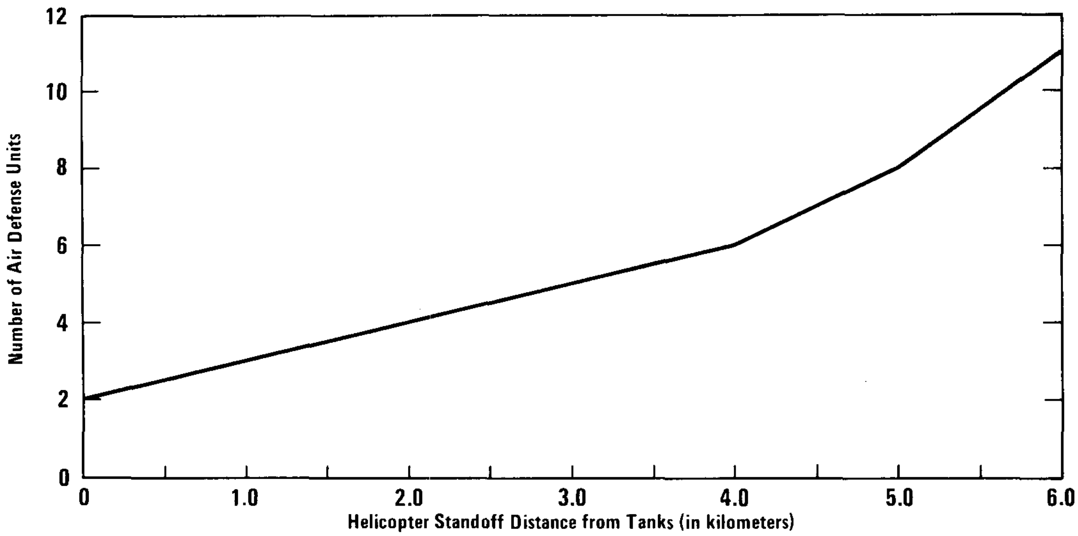
8. The probability of seeing a helicopter at a given range increases with the helicopter's altitudes. However, the variation in probability is slight within the likely range of altitude (10 to 30m) and is much more dependent on the range to the helicopter. (For example, the probabilities of seeing a helicopter five km away are 23 percent, 27 percent, and 30 percent at 10m, 20m, and 30m altitude, respectively.)

9. The desirability of having two air defenders in position to see each attacking helicopter results from the need to account for redundancy in case one air defense unit is unavailable because of (1) occupation with another target; (2) malfunction of equipment; (3) lack of ammunition; (4) missed detection; or (5) ground attack.

Figure 3.

Number of Air Defense Units Needed to Obtain Two Engagements Against An Enemy Helicopter



SOURCE: Congressional Budget Office.

defense weapon itself. By assuming that air defense units would be dispersed uniformly along a line that is parallel to the front line and one km behind the maneuver elements being attacked, the number of units per kilometer of front, or the needed density, can be calculated for the effective range of a given air defense system (see Figure 4). 10/

For an air defense weapon with a range of eight km, the density required for two engagements of a helicopter standing off five km is about four per every five km of front, or 0.8 per kilometer. The required density decreases as the range of the air defense system increases because longer-range systems can provide greater lateral coverage and be spread out more (see Figure 5). In order to provide two engagements of a helicopter standing

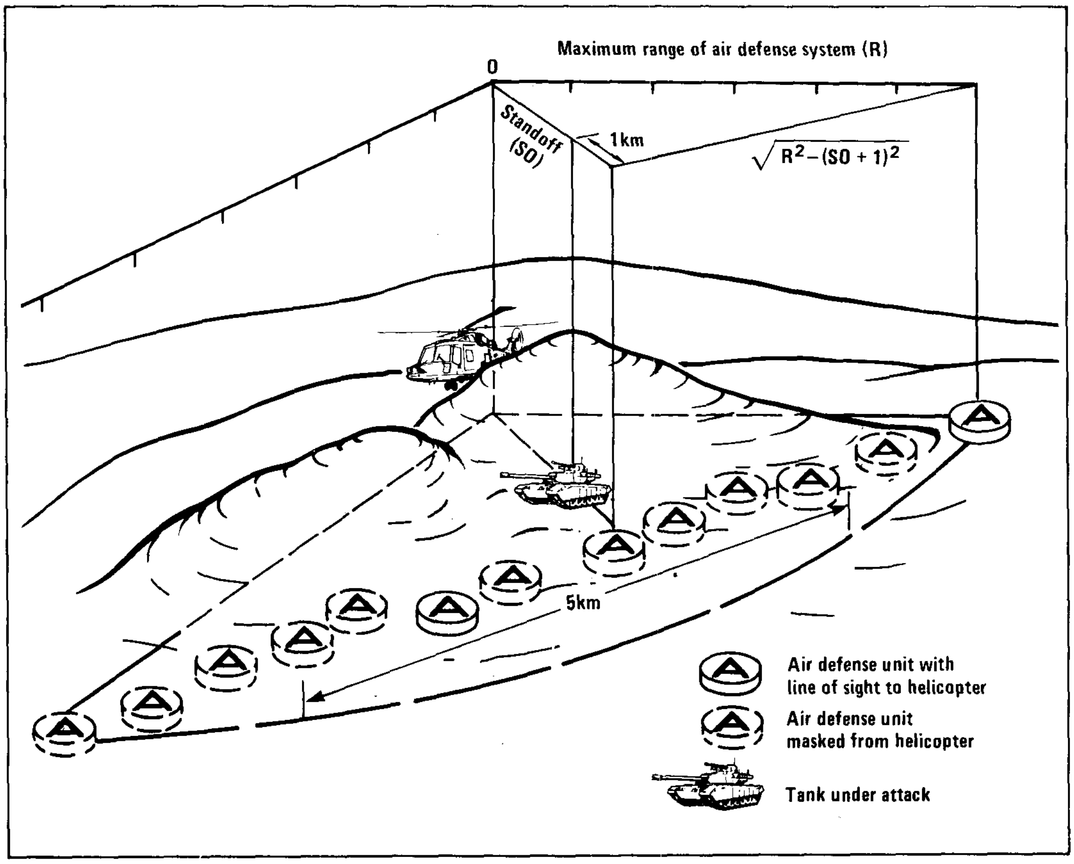
10. Although this assumption is a simplification of the irregularities of the battlefield, the total number of air defense units needed would not be greatly influenced by changing the actual positioning of specific air defense systems.

off six km away, between seven and eight air defense systems with a maximum effective range of eight km might be needed per every five km of front.

A five km front corresponds to the distance usually defended by a battalion task force. Thus, seven to eight air defense units could be needed

Figure 4.

Method for Determining Required Air Defense Density



SOURCE: Congressional Budget Office.

a. The required air defense density (per five km of front) is determined by the following relationship:

$$D = \frac{5N}{2\sqrt{R^2 - (SO + 1)^2}}$$

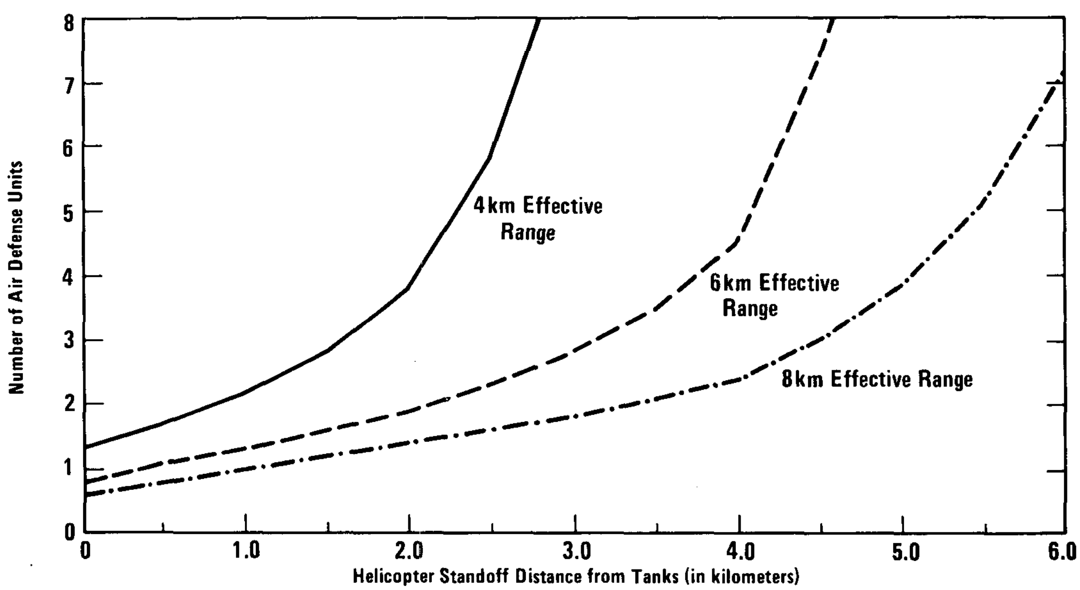
Where N is the number of air defense units required to ensure two sightings of a helicopter at a given standoff range;
R is the maximum effective range of the air defense system;
SO is the helicopter standoff range from the tank formations under attack.

to provide a battalion with enough air defense for two engagements per attacking helicopter. Since each heavy division typically includes 10 battalions, a total of 70 to 80 air defense units could be required to maintain the same level of defense throughout the division. In contrast, a division is currently defended by only 24 Vulcans. Thus, a much higher density of air defense units than that currently deployed would be needed to protect the forward maneuver units from standoff helicopters.

Affordability

The entire DIVAD program, designed to provide 36 DIVAD guns per division or about four guns per battalion, would have purchased a total of 614 air defense units. The total acquisition was estimated to cost over $4 billion, with each fire unit costing an average of $6.4 million. Using the DIVAD program as a precedent, it would be necessary to procure at least 1,200 weapons to provide each division with 70 to 80 air defense weapons.

Figure 5.
Number of Air Defense Units Needed Per Every Five Kilometers of Front



SOURCE: Congressional Budget Office.

Inasmuch as the DIVAD, at over $6 million per unit, was considered too expensive to purchase in quantities of 600 or so (one of the reasons for its cancellation), any weapon system bought in quantities of over 1,000 would have to be less expensive.

One possible source of savings lies in the type of target sensor associated with any potential air defense system. Two types of sensors are commonly used in modern air defense weapons--radars that emit and detect radiation reflected from the target and passive systems such as Forward Looking Infra Red Systems (FLIRs) that do not emit but rely on the visual or thermal signatures of the targets themselves for detection. Radars are, in general, more complicated and expensive than passive systems and often account for a large part of the cost of air defense weapons. In the case of the DIVAD gun, the radar and associated signal processing equipment accounted for 55 percent of the gun's unit cost.

The capability gained by including a radar on each air defense fire unit may not be worth the cost, although radar systems are indeed capable of locating targets at the longest ranges and over the widest area, as well as in the dark and all kinds of weather. While systems such as FLIRs can "see" helicopters or airplanes at longer ranges and in worse weather than the naked or aided eye, they do not have the range of radar nor can they typically cover a full 360° or even 180° sector. All methods currently used for target detection, however, must have a clear line of sight to the target--that is, neither radar nor FLIR nor eyeballs can see through hills, buildings, or, to a great extent, trees. Thus, although a radar could theoretically pick up a helicopter or plane at 10 or 20km, the likelihood that a clear line of sight will exist to low-altitude aircraft at such long ranges is small, particularly in Europe's hilly terrain. Therefore, providing an air defense system with radar might not greatly enhance its capability to detect low-altitude aircraft, at least not in Central Europe.

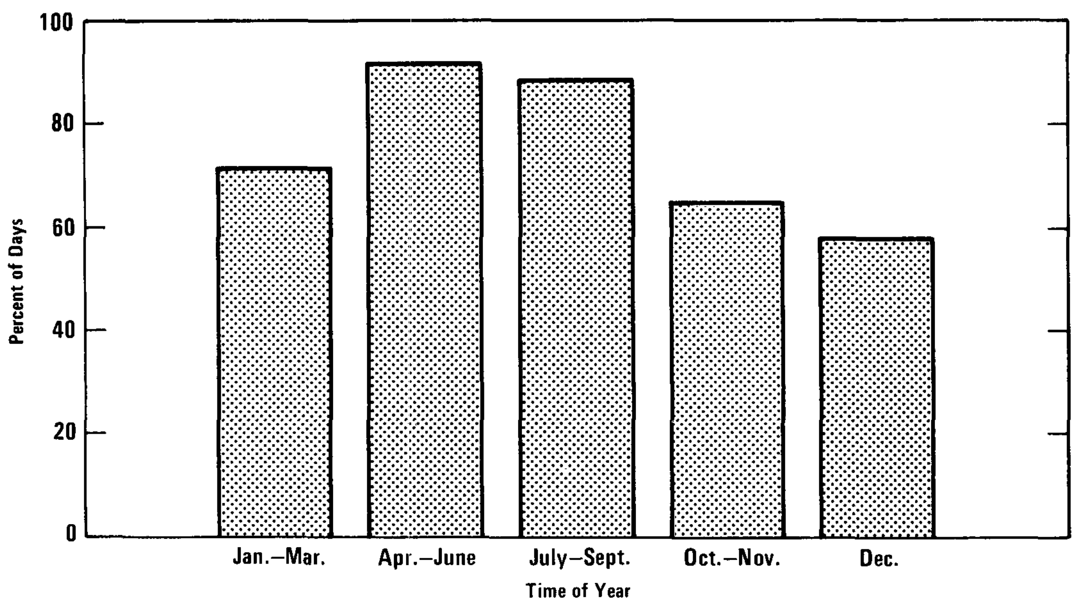
Nor is radar's all-weather capability always useful. Relative to passive systems such as FLIRs and visual systems, radar does work better in bad weather, and the weather in Central Europe, particularly during the winter months, can severely limit visibility (see Figure 6). Adverse weather works to the disadvantage of both attacker and defender, however, making it difficult for both to locate targets. As a result, attacking aircraft, particularly helicopters, might need to decrease their attack range, thus bringing them closer to the targets they are attacking and any air defenses located nearby. Furthermore, FLIRs can offset, to some extent, the effects of limited visibility in bad weather, since infrared light can often penetrate fog and mist that is impermeable to visible light. Finally, aircraft are not likely to fly in the type of weather that would prevent a FLIR from working, further negating radar's all-weather advantage.

Another argument against providing each air defense unit with radar is its marginal performance against low-altitude helicopters. The return radar signal from a hovering helicopter is very small. Whatever signal was received would be obscured to some extent by ground clutter--radar reflections from the nearby ground, trees and buildings. Finally, the enemy would attempt to hide aircraft signals further by jamming air defense radars or flooding them with synthetic electrical signals. The combined effect of small radar return, ground clutter, and enemy jamming makes radar detection of helicopters hovering at low altitude difficult.

Since air defense radars must emit radiation to work, they also alert enemy aircraft to the presence of opposing air defenses. Although at-

Figure 6.

Percent of Days in Germany with Visibility of Five Kilometers or Better



SOURCE: Congressional Budget Office from *Close Air Support,* Hearings before the Special Subcommittee on Close Air Support of the Senate Armed Services Committee, 92:1 (1971), p. 78.